Single Conversion LF Upconverter

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This upconverter is designed to directly translate the output from a soundcard from a PC running datamode software up to the final wanted transmission frequency. It is not necessary that the software generates a stereo quadrature output as this can be done in hardware, but if the stereo option is available, improved performance with regard to spurious outputs is possible

The upconverter adopts a single conversion image reject topology, and has been designed with reproducibility in mind – in particular there should be a minimum number of 'tweaks' needed to get it going. Two mixers are driven by quadrature local oscillator signals, with the audio input to each supplied with a 90 degree phase shift applied between them (I and Q channels). When the outputs from the two mixers are subsequently added, one mixer sideband is cancelled and the other reinforced.

Mixer

Initially a circuit using a pair of NE612 mixers was tried [1a] , but it proved impossible to achieve a carrier rejection better than 30dB. Opposite sideband suppression required considerable effort with phase and amplitude trimming to achieve a barely acceptable performance and this design was subsequently abandoned. A configuration using a pair of (now obsolete) MC1496 devices could achieve a more-than-adequate performance [1b] but the circuit is complicated by the need for external bias resistors and trimming, so was also rejected.

The solution finally adopted was based around an FST3125 bus switch quadrature mixer, as used in a number of HF SDR front end designs such as the Softrock receiver [2] . Unlike the well known Quadrature Sampling Detector (QSD) topology with its four successive 25% duty cycle pulses, a simple quadrature drive is adopted here which simplifies the drive circuit slightly and does not appear to detract from performance.

The circuit can be seen in the right hand part of Figure 1 and should be reasonably self explanatory. All four phases (0/90/180/250 degrees) are obtained from a synchronously clocked pair of flip flops driven at four times the wanted clock frequency. The external clock input has a buffer that allows an input of –10dBm or greater to properly clock the counter. Each phase drives one of four SPST bus switches.

Two unity gain op-amp buffers have a high input and a low output impedance. Drive to the mixer switches is through two 680 ohm resistors to essentially turn the drive into current sources. Each of these two audio signals are switched alternately to opposite sides of a balanced output transformer at LO rate, offset by 90° phase shift between the two channels. Accurate balance of the output transformer determines the carrier suppression that can be achieved, and is probably the only critical component. The primary must be a bifilar wound for accurate balance, and it is probably best if all three windings are wound in a trifilar fashion giving a transmission line transformer. 20 trifilar turns on a small low frequency ferrite torroid of uncertain heritage proved satisfactory down to well below 100kHz. The bus switches are biased to 2.5V on input and output ports to maximise their linearity; a common divider supplies all bias points.

To complete the mixer a simple low pass filter reduces harmonics. The component values shown cut off at 530kHz - these will have to be altered for operation at other frequencies..

IQ Source Generation

If stereo I/Q outputs are available from the transmit software, the mixer as described is all that is required to provide an image cancelling upconversion. All such software, for example that in [3], provides fine trimming of amplitude and phase and when correctly set up can give over 40dB of sideband rejection, over 50dB can sometimes be achieved with care.

Where I/Q outputs are not available, as is the case with most current datamode software, the 90° I/Q audio drives have to be generated in hardware. Many designs have appeared over the years, some with quite complex configurations giving acceptable full speech-band performance. However, these were usually used in zero-IF configurations where the unwanted product lay on top of the wanted signal, so a sideband rejection of 20dB was often adequate. Here we are not using a zero IF, so opposite sideband rejection is critical to performance.

For LF use, we are only really interested in a narrow audio range for low bandwidth modulations, and provided we restrict the audio to no more than a few hundred Hz in width, a remarkably accurate phase shift can be formed from a simple all-pass circuit configuration.

The circuit on the left hand side of Figure 1 shows the all-pass network which has been separated from the mixer stage to allow each part of this converter to be used on its own. See the note at the end for further simplification. Two preset resistors allow the frequency range and suppression to be traded-off. To see the range of values that can be achieved, an Excel spreadsheet is provided [4] that allows rejection to be plotted over the audio band as the all-pass component values are altered.

Alignment

It helps greatly if a wideband spectrum display that can show both output sidebands simultaneously, such as an SDR is used. Connect the converter output though an appropriate attenuator to the receiver input. If a wideband receiver is not available a normal SSB receiver can be used, either by tuning over the two sidebands, or by switching between LSB/USB reception.

Apply an audio tone of the desired frequency, and observe both sidebands and carrier leakage which should be around the –40dB region. There is no scope for adjusting carrier leakage (balance). If this is significantly worse than 40dB, it suggests an imbalance in the output transformer or incorrect connections or a damaged bus-switch chip. There is little scope for any other mechanism to degrade carrier rejection.

Ensure the correct sideband is selected; as shown the circuit is fixed for USB generation – swap I/Q channels to change to the other conversion direction. Adjust the two presets for the best sideband rejection.

A quick way to optimally align the all-pass network over a range of frequencies is to use broadband noise as the audio input rather than a single tone. The resulting spectrum will show the sideband cancellation over the whole frequency range. Suitable flat spectrum (white) noise, in the 200 – 3000Hz region can be obtained from an SSB receiver at maximum gain with no signal present, or from a PN code generator. Note that noise from FM and AM receivers is not white – that from an FM demodulator is particularly ‘spiky’.

Minor adjustments of amplitude balance between the I/Q drives to the mixer can be made by altering slighly the value of one or other of the two 680 ohm resistors in the mixer drive. This is easist to do by connecting an additional high value resistor in parallel while watching the rejection with an already optimised all-pass network. Changing the value by a fraction of a percent can make a further improvement to sideband rejection. Spot-frequency values of 50dB have been seen, although only over a width of a few tens of Hz.

Results

Figure 2 shows the output spectrum over a 10kHz bandwidth using an SDR-IQ receiver as the analyser. The audio drive for this plot consists of white noise (produced from a PN code generator) mixed with a sinusoidal tone of around 1500Hz. Here sideband rejection has been optimised for 1500Hz (the WSPR centre frequency) and it can be seen that a value of 37dB is achieved. The carrier leakage is just about visible at –36dB. In fact the converter is being driven at a few dB below its maximum drive level, and as carrier leakage is essentially fixed in it’s amplitude -40dBc or better is seen at maximum output.

Figure 3 shows a similar plot at 137kHz centre frequency – note that the carrier rejection is now better, it is not visible here and at least –45dBc. The all-pass network has been slightly adjusted for a more uniform response over 1000 – 1500Hz, but sideband rejection is still more than 35dBc.

After adjustment of channel balance, the 43dB sideband isolation of Figure 4 was obtained

Construction

You’re on your own here! No PCB, no hints apart from reiterating the need for accurate balance in the output transformer –the only component that critically affects carrier rejection. Figure 5 shows a photograph of my one and only version of the circuit – in true dead bug style.

Further Simplification

The combined upconverter can be simplified by combining the buffer opamp with the all-pass function. To do this remove the second opamp in each channel (the unity gain buffer), connect the outputs of the all-pass network direct to the 680 ohm resistors, and rebias the inputs to 2.5 V instead of around 6V as in the original. *This configuration has not been tested*.

Conclusions

The performance achieved, with sideband and carrier rejection in the –40dBc region is probably the best that can reasonably be expected from a simple design such as this.

More complex designs with a lot of effort applied to adjustment ought to manage slightly better, but this level is probably acceptable for most practical purposes. In particular, a sideband rejection of –40dBc, which at LF will probably result in out of band signals, is considered to be an acceptable level of spurious products by many authorities.
It is up to you to decide if this rejection figure is acceptable or not!

References

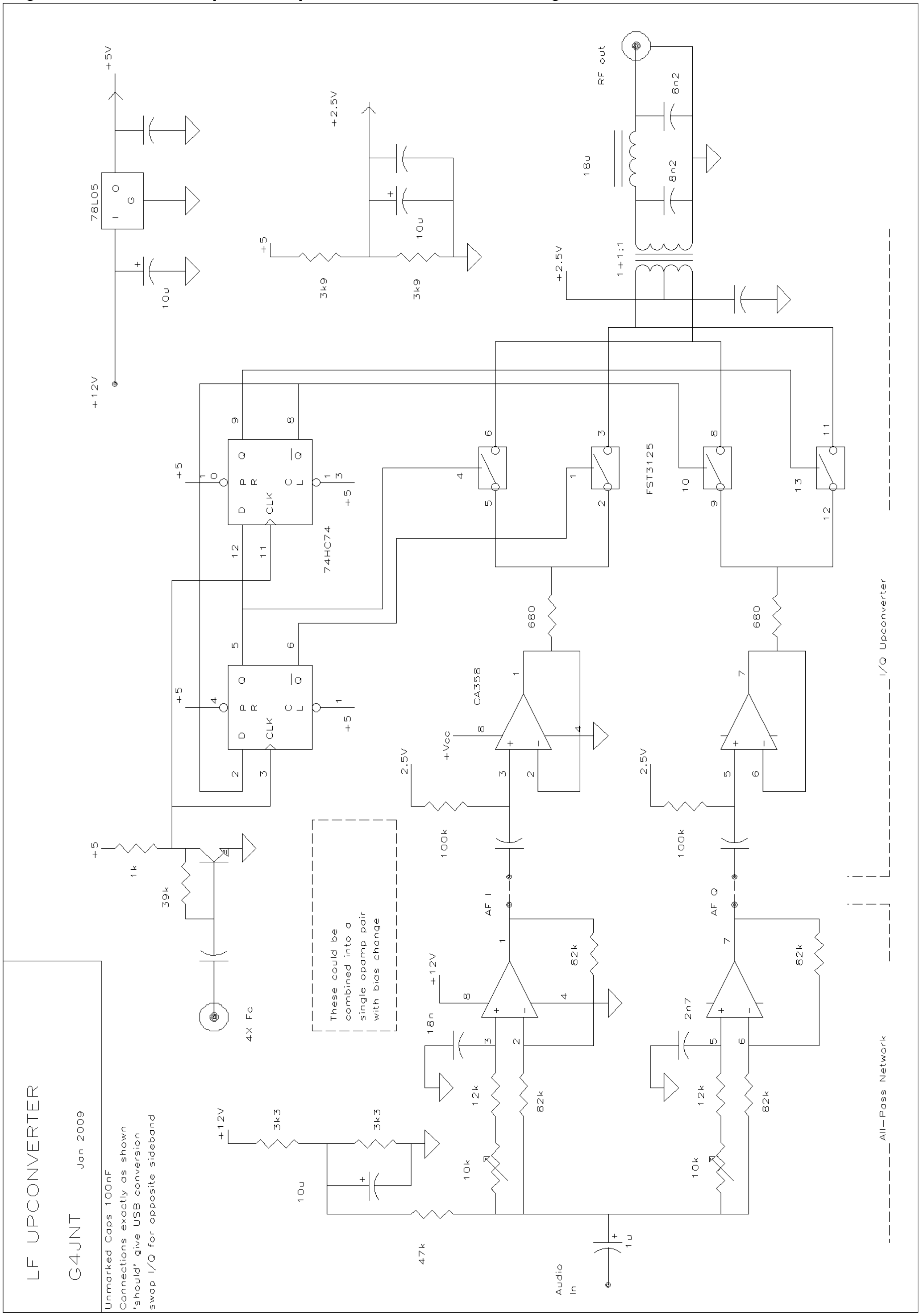
[1a] - http://www.g4jnt.com/IQConverters.htm Fig 3
[1b] - " " " " " FIg 1

[2] - http://www.softrockradio.org/node/1

[3] - G3PLX SDR transmitter software
http://www.g4jnt.com/SDRTxSW.htm

[4] - http://www.g4jnt.com/OPA_AllPass.xls
Alter the values of C1 R1 C2 R2 to see how the rejection vs. frequency response alters.

Figure 1 - Complete Upconverter circuit diagram



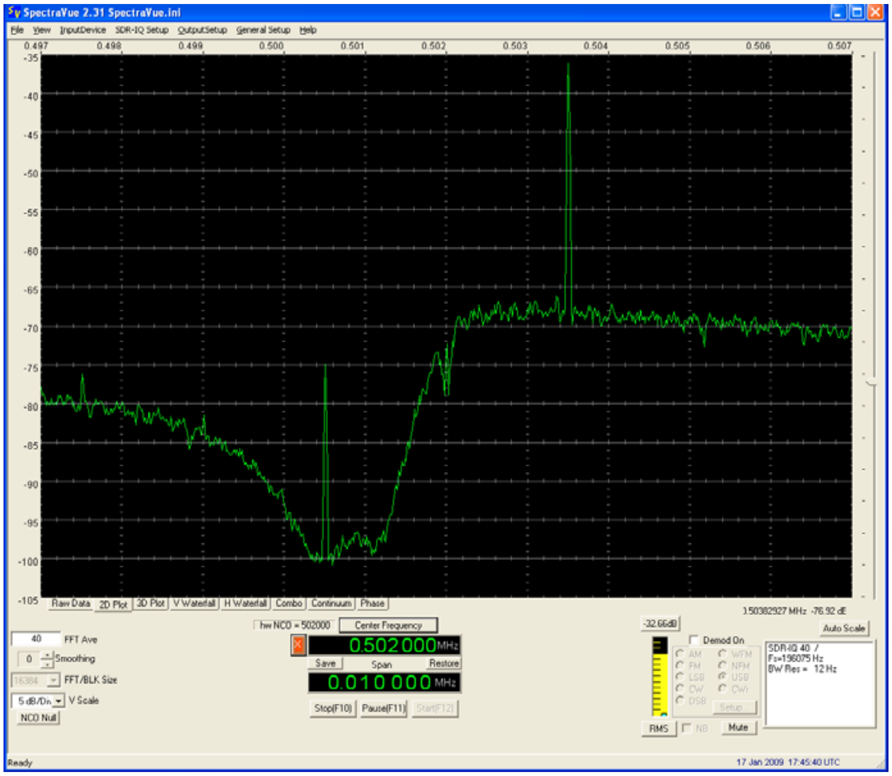


Figure 2 - AF Drive Broadband noise source + 1.5kHz tone
All-pass network optimised for 1.0kHz and 1.5kHz
Centre Freq   502kHz

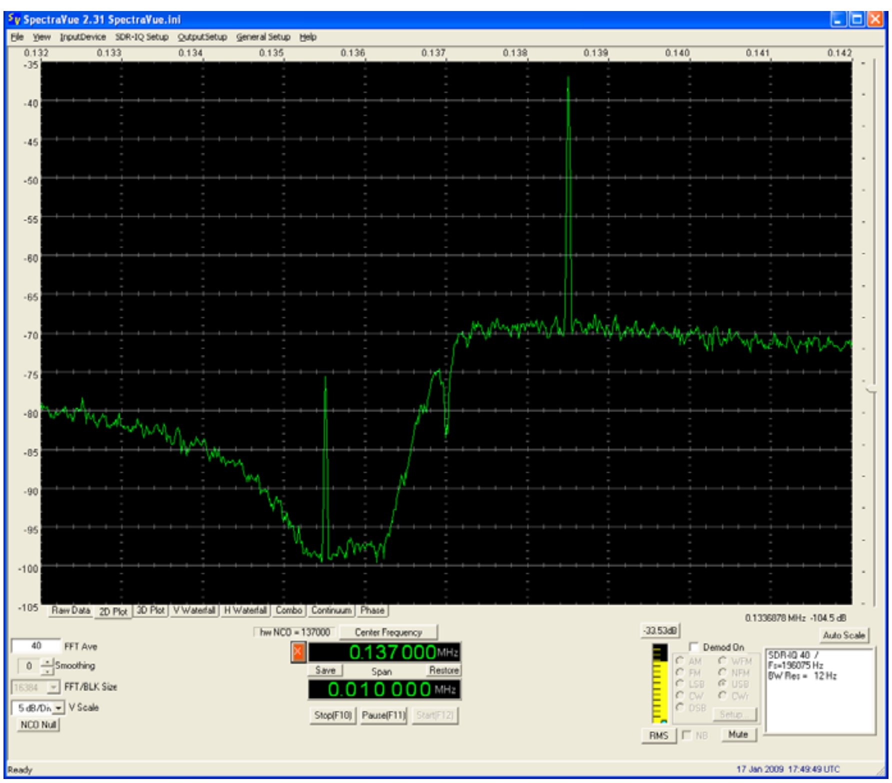


Figure 3   Centre Freq 137kHz , adjusted all-pass network

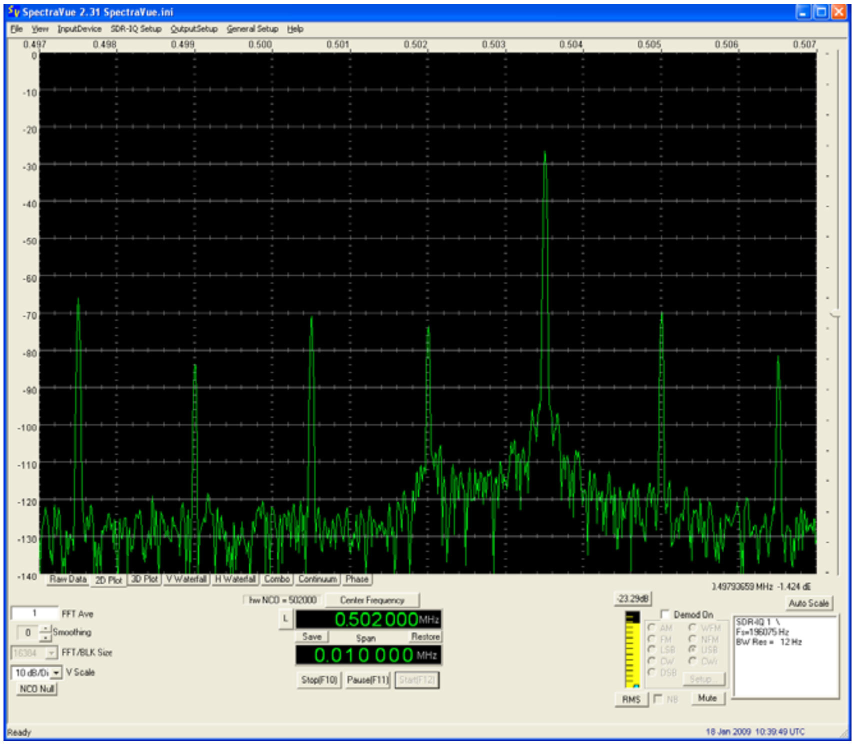


Figure 4 Sideband isolation at 1500Hz improved by fine adjustment of amplitude balance. (No noise signal)

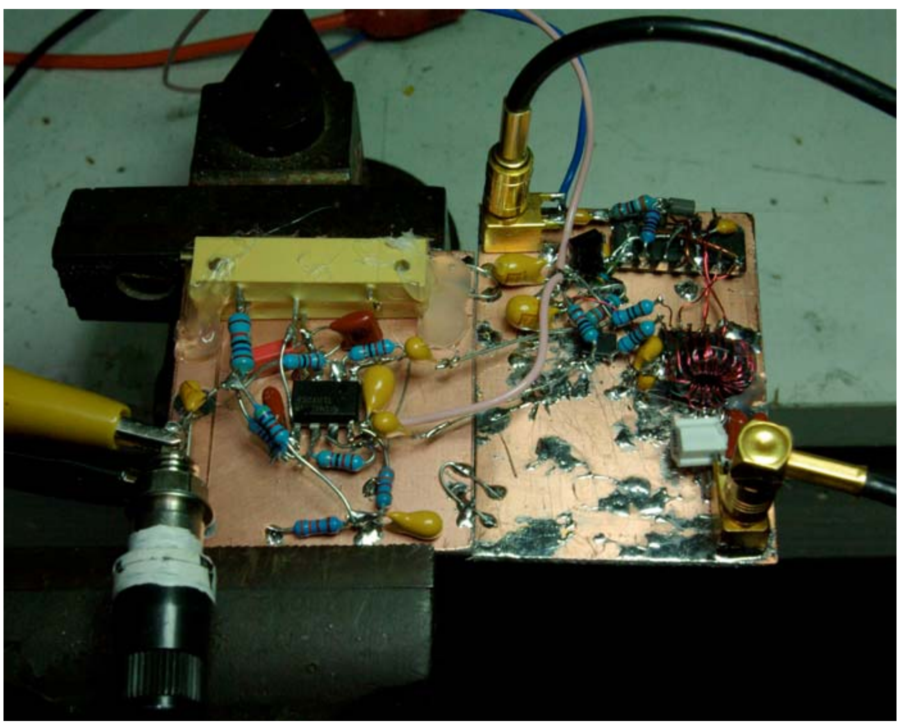


Figure 5 - The finished thing!